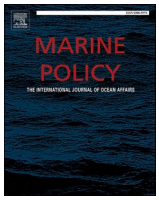
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Economic instruments for marine invasive alien species management in the Mediterranean

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ABSTRACT

Invasive alien species (IAS) in the Mediterranean impose increasing ecological and economic burdens on key sectors such as fisheries, aquaculture, and tourism, yet management remains predominantly reactive. This study examines how economic and financial instruments can internalize invasion-related externalities and support preventive, cost-effective responses. A suite of tools, ranging from removal subsidies and compensation funds to Pigouvian taxes, tradable permits, and performance bonds, offers pathways to embed ecological risk into fiscal and policy frameworks. Examples from the region, including lionfish and pufferfish removal incentives and blue crab market valorization, demonstrate how targeted measures can simultaneously reduce IAS impacts and sustain local livelihoods. Compensation for IAS-driven stock declines underscores the importance of financial support for affected communities, while taxation and permit schemes can signal risks and discourage high-impact activities. Persistent challenges include limited valuation data, fragmented governance, and unequal feasibility between EU and non-EU countries. Strengthening green budgeting practices, public–private partnerships, and markets for IAS-derived products offers underexplored opportunities to align economic incentives with conservation goals. By reviewing existing applications and policy frameworks and identifying gaps, the paper proposes pathways to integrate economic instruments into regional action plans under the United Nations Environment Programme / Mediterranean Action Plan and the Barcelona Convention. Institutional diversity within the Mediterranean region presents both challenges and opportunities to advance financial innovation in IAS management and strengthen transboundary cooperation.

1. Introduction

The spread of IAS poses a critical and escalating threat to marine ecosystems worldwide [19]. These species, introduced through both deliberate and accidental pathways, can displace native taxa, disrupt food web dynamics, and degrade essential habitats. The resulting ecological disruptions often cascade into social and economic sectors, notably affecting fisheries, aquaculture, and tourism [37]. Among the principal drivers of marine IAS introductions are maritime trade and transport. Key vectors include ballast water discharge, hull fouling, and escape from aquaculture installations [30]. The scale of these pathways is substantial: the International Maritime Organization (IMO) estimates that around ten billion tonnes of ballast water are moved annually across global waters, enabling widespread species translocation [18]. As shipping intensifies and climate conditions shift, forecasts suggest a 36 % increase in marine invasion rates by 2050, with invertebrates in European waters particularly at risk [36].

The Mediterranean Sea exemplifies this intensification of marine bioinvasions. Due to its semi-enclosed nature and dense maritime traffic, it has become the most biologically invaded marine basin globally, with nearly 1000 non-indigenous species (NIS) documented to date. Approximately 63 % of these introductions are linked to the Suez Canal, a man-made corridor that connects the Red Sea with the eastern Mediterranean [15,22]. This biogeographic conduit, opened in 1869 and substantially deepened and widened over time, has facilitated what is known as Lessepsian migration as the movement of thermophilic Indo-Pacific species into Mediterranean waters. The most recent canal expansion in 2016 has further amplified these flows, compounding the ecological and economic repercussions across the region [16]. Initially intended to improve global shipping efficiency, the Suez Canal has unintentionally reshaped marine biodiversity patterns in the Mediterranean, connecting two historically distinct marine realms.

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Among the most impactful IAS now established in the region are *Siganus* spp. (rabbitfish), *Pterois miles* (lionfish), and *Lagocephalus sceleratus* (pufferfish), all of which exert profound ecological pressure on native communities. While freshwater and wetland habitats have also experienced NIS introductions, especially in deltas and estuarine zones, the most significant concentration of impacts remains in marine environments, particularly among mollusks, decapods, and fish [15,44]. In addition to the Suez Canal, vectors such as hull fouling, ballast discharge, and the aquarium trade continue to contribute to species introductions [12,30].

This paper builds on, and significantly extends, a broader policy-oriented initiative supported by Plan Bleu as one the Regional Activity Centers of the Mediterranean Action Plan (MAP) of United Nations Environment Programme (UNEP), which aims to strengthen the evidence base for sustainable public finance reforms in the Mediterranean region [34]. It investigates the economic dimensions of marine IAS in the Mediterranean, with particular attention to the financial burdens borne by key sectors and the costs associated with control and management interventions (Fig. 1). The conceptual structure of marine bioinvasion follows a progression from ecological to economic impacts, then to the enabling management and policy context, and finally to the corresponding response and intervention measures. Economic impacts encompass both direct sectoral losses, such as those affecting fisheries, aquaculture, and tourism, and indirect management and control costs. The management and policy frameworks represent the institutional conditions, governance, coordination, research, and finance, that enable responses, while the response and intervention measures include preventive, corrective, and restorative actions, such as market-based tools and regional cooperation (Fig. 1). A range of economic support tools, including removal subsidies, compensation mechanisms, and market-based incentives, were evaluated to assess their potential role in mitigating economic losses. Policy gaps and governance constraints were further identified by outlining strategies for integrating ecological risk into economic planning and regional IAS governance.

This study advances the literature by framing economic instruments as practical mechanisms for embedding ecological risk within Mediterranean governance systems, bridging environmental economics with marine policy application. Beyond describing existing tools, it develops a conceptual framework that links economic incentives with preventive and adaptive management of marine invasive species. The analysis adds a regional and comparative perspective by assessing how such instruments can be operationalized under diverse fiscal and institutional settings. In light of this, the paper aims to strengthen both theoretical understanding of incentive-based governance and its practical implementation across transboundary bioinvasion contexts in the Mediterranean region. Economic approaches to invasive-species management have been increasingly examined within both global [17,33] and Mediterranean policy frameworks [42]. Yet, their translation into regional governance remains limited, providing the rationale for the present study.

2. Economic impacts and governance challenges

Biological invasions exert considerable and persistent economic pressure across the Mediterranean region, particularly on fisheries, aquaculture, tourism, and coastal infrastructure. Unlike terrestrial systems, where containment measures may be feasible, the fluid and interconnected nature of marine environments makes IAS control especially difficult once populations are established. Their spread often leads to sustained costs over time. Total IAS-related economic impacts in

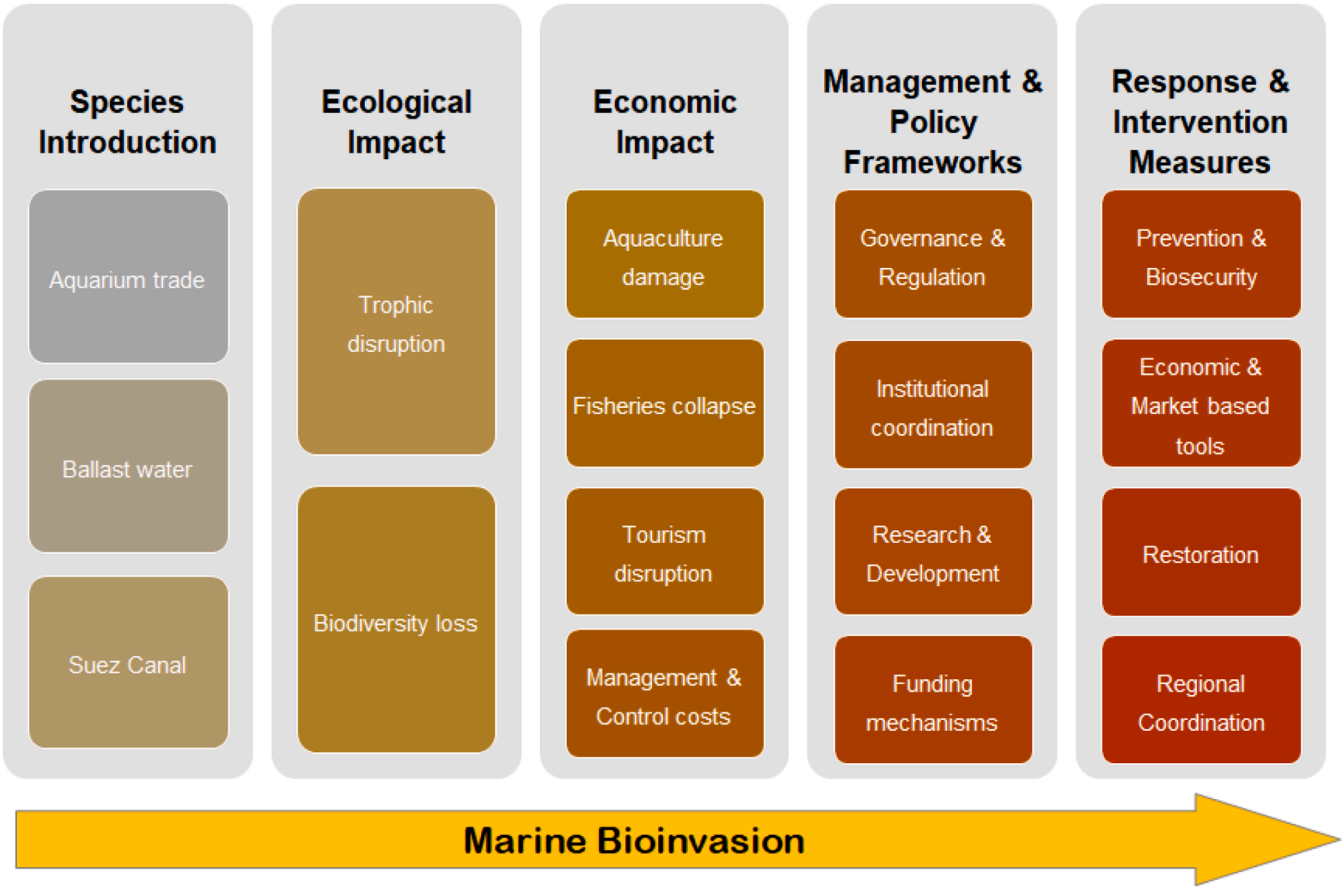


Fig. 1. Conceptual pathway illustrating the progression from marine bioinvasion to ecological and economic impacts, followed by management and response measures in Mediterranean context.

the Mediterranean have been estimated at USD 27.3 billion, with USD 3.6 billion in realized costs reported over the past thirty years [25]. These figures primarily reflect damage-related expenditures rather than investment in proactive management, illustrating the reactive nature of current IAS strategies. In the absence of effective eradication options, economic losses continue to accumulate across sectors.

Regional cost estimates further underscore the magnitude of these impacts. In Italy alone, the cumulative cost of marine IAS reached approximately €818 million between 1970 and 2020, with fisheries, aquaculture, and coastal infrastructure representing over 60 % of the total ([45]; Cianfanelli et al., 2023). Comparable valuations in other Mediterranean countries remain fragmentary, yet available evidence indicates that annual IAS-related losses already exceed the combined budgets allocated to marine-conservation programmes in several North African states [25]. These figures highlight a persistent mismatch between ecological risk and economic preparedness, reinforcing the need for integrated financial instruments capable of internalizing invasion-related externalities.

2.1. Fisheries and aquaculture

Mediterranean fisheries have been heavily affected by IAS, with invasive species contributing to declines in native stocks and inflicting physical damage to gear. Species such as the toxic silver-cheeked toadfish (*Lagocephalus sceleratus*) and herbivorous rabbitfish (*Siganus* spp.) have disrupted ecological balances and undermined commercial catches [45]. These species compete with native fauna for food and habitat, and in some cases prey directly on commercially valuable species. The toxicity of pufferfish further reduces the market value of landed fish, exacerbating economic losses. Fishers report reduced catch volumes, increased gear maintenance costs, and price suppression, all of which contribute to the erosion of livelihoods in vulnerable coastal communities [24].

Aquaculture operations face parallel challenges. Invasive decapods and mollusks such as the green tiger prawn (*Penaeus semisulcatus*) compete with farmed species, while macroalgae and fouling organisms increase maintenance and infrastructure costs. Invasive biofouling affects filtration systems and cage stability, driving up operational expenditures [25]. These impacts underscore the need for targeted economic instruments to protect aquaculture viability and support adaptive responses.

2.2. Tourism and coastal infrastructure

IAS also compromise the Mediterranean's coastal tourism sector, a major source of revenue for many regional economies. Jellyfish blooms and macroalgal overgrowth reduce the recreational appeal of beaches and coastal waters, affecting visitor numbers and revenue [14,43]. The Indo-Pacific jellyfish *Rhopilema nomadica* has become widespread in the eastern Mediterranean, forcing municipalities to deploy expensive mitigation strategies such as protective nets and clean-up operations [21].

Similarly, an algae species like *Caulerpa taxifolia*, introduced through the aquarium trade, degrade underwater habitats and reduce the attractiveness of diving and snorkeling destinations. These impacts affect small tourism operators and ecotourism businesses, adding another layer of financial strain to communities already facing marine ecosystem changes [21].

2.3. Regional economic disparities

The distribution of IAS-related costs is not uniform across the Mediterranean. Countries bordering the eastern basin, particularly in the Levantine region, are disproportionately affected due to their proximity to the Suez Canal and warmer conditions that favour thermophilic species [21]. Although the western Mediterranean has historically experienced fewer incursions, rising sea temperatures have facilitated the westward expansion of several IAS, gradually increasing the economic toll. Countries such as France, Spain, and Italy report higher documented losses, in part due to more robust monitoring and reporting infrastructure. By contrast, countries like Libya have fewer published estimates, likely reflecting gaps in monitoring capacity rather than lower exposure [25].

2.4. Financial challenges

Managing marine invasions entails high costs, including those associated with control, surveillance, and restoration. In many cases, however, long-term funding arrangements are absent, resulting in fragmented or short-lived responses [38,5]. Although the financial burden is substantial, most expenditures remain reactive, with limited investment in risk reduction or prevention. To address these funding gaps, the adoption of proactive green budgeting practices is usually crucial.

Green budgeting refers to the systematic integration of environmental and climate objectives into public financial management and fiscal-policy frameworks. It aims to align budgetary decisions with sustainability goals by tagging, tracking, and evaluating expenditures and revenues according to their environmental impact [11,32,31,10]. In the context of IAS management, green budgeting enables governments to embed preventive and restoration measures within national fiscal systems, ensuring continuity beyond project-based funding cycles.

Empirical studies highlight that high-income countries with robust institutional frameworks (e.g. France, Italy, and Spain) have often led the way in integrating such tools [6]. In contrast, many Southern and Eastern Mediterranean countries continue to face obstacles in systematically deploying these instruments, due to limited technical capacities, occasionally unstable regulatory frameworks, and insufficient fiscal resources [13].

Economic incentives for IAS management remain in their infancy. There is limited use of tools such as financial compensation, subsidies for removal, or payments for ecosystem protection. Strengthening cross-border cooperation and developing sustainable funding mechanisms are essential to reduce long-term costs and foster coordinated regional responses.

2.5. Institutional landscape and regulatory gaps

Governance of marine IAS in the Mediterranean is shaped by a patchwork of international, regional, and national instruments. The European Union's Regulation 1143/2014 provides a structured framework for IAS management, emphasizing prevention, early detection, and rapid response [9,22]. Additionally, the Marine Strategy Framework Directive (MSFD) integrates IAS control within broader marine environmental goals, linking it to the achievement of Good Environmental Status (GES) in EU waters. The recent implementation of the EU Nature Restoration Regulation also presents a significant opportunity to enhance the resilience of marine habitats in the EU Mediterranean, and, it is hoped, eventually in non-EU Mediterranean countries as well [1].

At the regional level, UNEP/MAP initiatives and the Barcelona Convention promote cooperation among both EU and non-EU countries (UNEP-MAP, 2003). Under its Protocol concerning Specially Protected Areas and Biological Diversity (SPA/BD Protocol adopted in 1995), UNEP/MAP recommends concrete protection measures to safeguard elements of biological diversity through Action Plans and technical tools for inventory. The Protocol recommends setting up Specially Protected Areas of Mediterranean Importance (SPAMIs), including trans-boundary areas, in areas where several states have sovereignty and in international waters. Meanwhile, the Mediterranean Strategy for Sustainable Development (MSSD) 2016–2025 acknowledges Invasive Alien Species (IAS) as one of the key pressures contributing to the degradation of Mediterranean marine and coastal ecosystems [41]. The 2012 Report on the

State of the Mediterranean Marine and Coastal Environment, referenced in the strategy, identifies invasive non-indigenous species alongside marine litter, chemical pollution, and overfishing as major drivers requiring coordinated policy responses. Additionally, IAS are explicitly listed under Objective 2 of the MSSD, which promotes sustainable resource management and ecosystem protection, recognizing them as a threat to natural resources and food security.

However, implementation remains uneven, with non-EU states often facing institutional and financial constraints [7,25]. Internationally, the Convention on Biological Diversity (CBD) includes IAS as a priority under Article 8(h), and the IMO Ballast Water Management Convention sets specific obligations for reducing ship-borne introductions [3,18].

Despite this policy architecture, the prevailing approach remains reactive, with insufficient attention to long-term financing and incentive structures. Regulatory asymmetries across countries further hinder coordinated action, highlighting the need for integrated strategies that bridge ecological, economic, and institutional dimensions of IAS management. The following section explores how economic and financial instruments complement existing regulatory frameworks to operationalize IAS management across the Mediterranean.

3. Financial instruments and market-based approaches

A range of financial instruments has been proposed to mitigate the economic burdens caused by IAS and to incentivize preventive action, particularly in high-risk sectors. The typology of economic tools presented here draws on established classifications in environmental and resource economics that outline the theoretical foundations of market-based instruments [17,2,32,33]. Building on these concepts, the analysis integrates insights from recent regional policy frameworks, which focus on sustainable public-finance reforms in the Mediterranean context [34], adapted here to the case of invasive-species management. This typology was adapted to reflect both implemented and proposed mechanisms for invasive-species management. Market-based instruments such as taxes, tradable permits, insurance schemes, and targeted subsidies provide pathways for internalizing the external costs of biological invasions and enhancing compliance with biosecurity regulations (Fig. 2).

To improve comparability and clarity, the typology was developed through a targeted review of peer-reviewed publications and relevant grey literature. Key studies on marine policy and environmental economics in the Mediterranean and comparable systems were complemented by regional assessments. The findings enabled classification of instruments by maturity, theoretical, piloted, or implemented, and by geographical scope, distinguishing those applied within the Mediterranean from global conceptual examples. The findings enabled classification of instruments by maturity, theoretical, piloted, or implemented, and by geographical scope, distinguishing those applied within the Mediterranean from global conceptual examples. The resulting typology (Fig. 2) illustrates the spectrum of economic tools according to their functional role along the invasion-management continuum and their degree of implementation in the Mediterranean. The classification presented in Fig. 2 follows a functional logic along the invasion-management continuum: prevention instruments internalize ecological risk prior to introduction, compensation instruments address post-impact liabilities, and market-development instruments create positive incentives for control and utilization.

Among these instruments, only a subset has reached operational status in the Mediterranean, distinguishing between implemented, piloted, and theoretical tools. Table 1 complements this typology by summarizing key economic instruments, their policy alignment, feasibility across EU and non-EU Mediterranean contexts, main advantages and challenges, and representative examples of application. One widely discussed approach is the application of Pigouvian taxes, which place financial responsibility on actors contributing to the spread of IAS. These taxes aim to reflect the true social costs of activities such as ballast-water discharge, ornamental-species trade, and aquaculture imports, thus encouraging shifts toward lower-risk alternatives [2]. By embedding environmental externalities into market prices, such taxes can both deter harmful practices and promote the competitiveness of sustainable options. However, establishing appropriate tax levels remains challenging, given uncertainties around invasion probabilities and the difficulty of monetizing long-term ecological damages [33]. Additional tax-based instruments, such as customs duties combined with border inspections, have also shown potential. McAusland and Costello [29] demonstrated that the optimal level of these duties increases with the probability of IAS introduction, and several countries, including Austria and New Zealand, have implemented inspection fees on imports to recover biosecurity-related costs [5].

Tradable permit systems have also been proposed as a mechanism to

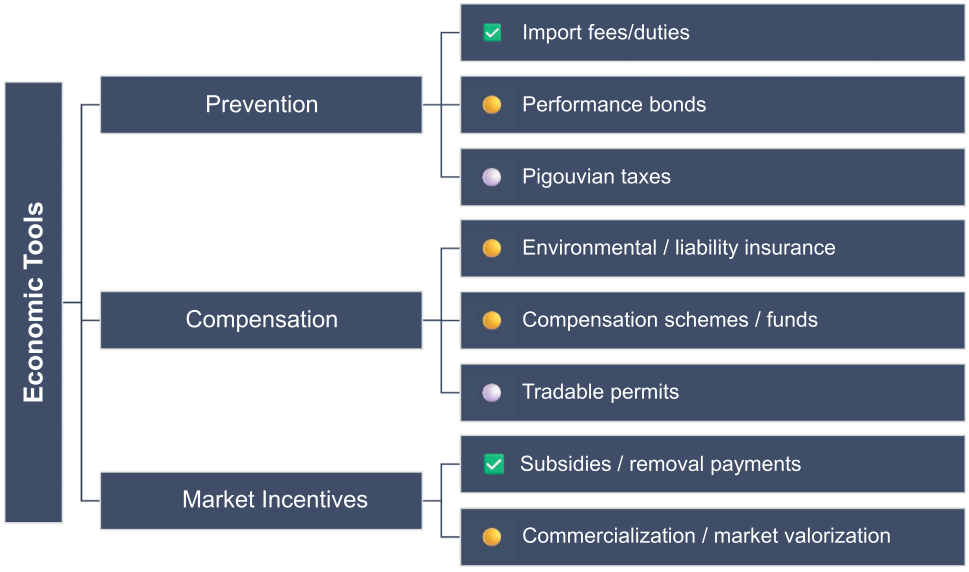


Fig. 2. Typology of economic tools for marine IAS management, classified by function (prevention, compensation, and market incentives) and by implementation status in the Mediterranean (✓ implemented; piloted; theoretical). Classification and status are based on evidence from Mediterranean and analogous marine systems (e.g. [2,27,23]

Table 1
Overview of economic tools for IAS management in the Mediterranean (F: Feasibility EU/Non-EU: Mediterranean countries that are members or non-members of the European Union; H: High, M: Medium, L: Low; IMO: International Maritime Organization; CBD: Convention on Biological Diversity; EU MSFD; European Union Marine Strategy Framework Directive; EU IAS Regulation: Regulation (EU) 1143/2014 on the prevention and management of the introduction and spread of invasive alien species; UNDP: United Nations Development Programme; UNEP/MAP: United Nations Environment Programme / Mediterranean Action Plan; LIFE: EU LIFE Programme for Environment and Climate Action).

Economic Tool	Policy Alignment	FeasibilityEU/ Non-EU		Key Advantage	Main Challenge	Regional Example
Import Fees / Duties	IMO Ballast Water Convention; CBD	M	L	Recovers costs for biosecurity controls at ports	Administrative complexity and variable enforcement	Implemented in New Zealand for ballast-water inspection fees; Austria applies inspection-related port charges for biosecurity [5,29]
Performance Bonds	Regional conventions / Aquaculture licensing	L	L	Incentivizes compliance and preventive behavior	High administrative cost; difficult to manage in open-water systems	Proposed for mariculture operations in France and Greece to ensure habitat restoration after lease termination [2]
Pigouvian Taxes	CBD; IMO Ballast Convention	M	L	Internalizes ecological risk and discourages high-risk trade	Hard to quantify optimal tax and invasion probability	Conceptual applications for aquaculture imports and ornamental trade proposed in Italy and Spain [2,33]
Environmental / Liability Insurance	CBD; EU Directives; MSFD	M	L	Ensures funding for remediation and restoration	Complex liability attribution between operators	Piloted in aquaculture and shipping sectors in Italy and France under environmental-liability schemes [2,32]
Compensation Funds / Public Support	EU Funding Schemes (LIFE, MSFD)	M	M	Supports restoration and recovery measures	Dependent on external project funding cycles	EU LIFE projects addressing habitat restoration from *Caulerpa* invasion in France and Spain [45]
Tradable Permits	Market-based EU Policies	L	L	Market-driven compliance incentives	Needs robust monitoring and traceability	Theoretical proposal for biosecurity credits modeled on carbon markets [5]
Subsidies / Removal Payments	MSFD; EU IAS Regulation	H	M	Promotes active IAS removal; supports fisher livelihoods	Risk of perverse incentives; requires adaptive management	Implemented for pufferfish (*Lagocephalus sceleratus*) in Turkey, lionfish (*Pterois miles*) in Cyprus and Greece, and blue crab (*Callinectes sapidus*) in Italy (Adriatic) [24,39,27]
Commercialization / Market Valorisation	UNDP Innovation Initiatives; MSFD	M	M	Creates market value for IAS; diversifies income sources	Market viability declines as populations decrease	Lionfish commercialization campaigns in Cyprus and Greece; pufferfish by-product innovation (ecological leather) under UNDP-Turkey program [40,23]

cap the translocation of potentially invasive species. These systems allocate a fixed number of permits that authorize specific introductions or movements, allowing businesses to trade unused allowances within a regulated market. While this approach has proven effective in carbon markets, its application in the context of IAS remains largely theoretical and untested [5].

Other financial tools, such as compensation schemes, performance bonds, and environmental/liability insurance, aim to ensure that industries engaged in high-risk activities bear responsibility for potential IAS introductions. Insurance schemes require operators in sectors like shipping and aquaculture to maintain financial coverage, which can be mobilized for mitigation and restoration in the event of an invasion [2]. Similarly, performance bonds obligate companies to deposit a refundable sum, which is returned only if biosecurity protocols are followed and no IAS introduction occurs. These mechanisms create financial safeguards to support response efforts but face implementation barriers in marine systems, including difficulties in tracing responsibility and high administrative burdens [5].

Direct incentives, particularly subsidies and removal payments, have proven effective in operational IAS control. Several Mediterranean countries have implemented targeted incentive schemes for fishers, offering financial compensation for the removal of priority IAS. In Turkey and Cyprus, for instance, programs encourage fishers to target *Pterois miles* (lionfish) and *Lagocephalus sceleratus* (pufferfish), integrating IAS control into routine fishing activities [19,24,35,39]. In parallel, an innovation program supported by UNDP has encouraged the development of sustainable commercial uses for pufferfish byproducts, including the production of ecological leather, further contributing to long-term removal incentives through market-based approaches [40]. By creating commercial value for invasive species, these initiatives help lower IAS densities while diversifying income sources for small-scale fishers. Another good example is the management of blue crab (*Callinectes sapidus*) in Adriatic Sea: as the regional authorities in Italy have introduced subsidies to support targeted blue crab harvesting, covering fuel and trap-related expenses. These efforts are complemented by initiatives to promote the crab as a valuable food resource, with public campaigns and market development strategies encouraging its incorporation into local seafood cuisines [45,5]. Such consumption-based approaches offer a dual benefit of controlling IAS populations while supporting fisher incomes, provided they are embedded within adaptive management frameworks and avoid creating perverse incentives [19,27]. Studies also emphasize the importance of aligning these interventions with local culinary traditions and cultural contexts to maximize their social acceptability and effectiveness [28,8].

The experience with lionfish (*Pterois miles*) in Cyprus and Greece exemplifies how market creation and consumption incentives can align ecological control with local economic benefits. Kleitou et al. [23] reported that the emergence of a commercial lionfish fishery, supported by awareness campaigns and culinary promotion, has contributed to reduced local densities and new income opportunities. Similar market-oriented initiatives elsewhere have demonstrated that while commercial demand can initially support effective population control, declining catches often undermine long-term market stability and fisher engagement [26]. Yet, lessons from comparable initiatives in the Caribbean and Mexico caution that sustained governance oversight is essential to avoid perverse incentives when populations decline (López-García et al., 2023). A similar adaptive mechanism has emerged for the blue crab (*Callinectes sapidus*) in the Adriatic, where Italian regional authorities combined targeted subsidies with market development campaigns. This approach not only incentivized removal but also fostered local seafood diversification and cultural acceptance [5,45,27].

A comparative synthesis of these mechanisms reveals distinct strengths and trade-offs. Theoretical instruments, though economically efficient on paper, face barriers to adoption due to governance fragmentation and uncertain ecological baselines. Piloted mechanisms, such as insurance and liability schemes, demonstrate accountability potential but require regulatory harmonization and reliable attribution of biosecurity failures. Implemented instruments, while more feasible, depend heavily on public funding and market acceptance. Their success thus hinges on adaptive governance that links fiscal incentives to measurable

ecological outcomes and periodically re-evaluates cost-effectiveness under changing invasion dynamics and market conditions [19,25,32].

Beyond reactive measures, financial support for research and innovation plays a key role in building long-term resilience. EU-funded programs have supported the development of ballast water treatment systems and funded restoration efforts targeting seagrass meadows (*Posidonia oceanica*) degraded by IAS [17,20]. Investments in early detection technologies, including environmental DNA (eDNA) monitoring, have significantly improved the capacity for timely and cost-effective response [4]. Public investment in such technologies enhances regional preparedness and supports evidence-based management across Mediterranean jurisdictions.

Despite these advances, several challenges persist. Many existing financial mechanisms rely on short-term grants or project-based funding, limiting their sustainability. This problem is especially acute in non-EU Mediterranean countries, where fiscal constraints hinder long-term IAS response [19]. Moreover, prevailing economic models often fail to incorporate complex ecological feedbacks and local socioeconomic dynamics, limiting their effectiveness in guiding policy [24]. Data gaps on the economic impacts of IAS further restrict cost-benefit analyses and weaken the basis for tailored financial interventions [38].

When compared across categories, preventive instruments such as Pigouvian taxes or tradable permits present strong theoretical efficiency but remain constrained by data scarcity and enforcement complexity in the Mediterranean. Compensation-based instruments, including insurance and performance bonds, offer accountability but face institutional barriers due to limited traceability of IAS introductions. By contrast, market-development approaches, such as removal subsidies or the market valorization of lionfish and blue crab, show greater short-term feasibility, especially within small-scale fisheries contexts, yet require adaptive management to avoid over-exploitation [2,24,27,23] . Experience from other regions shows that once harvest-driven control reduces invasive populations, diminishing returns can undermine market viability and discourage continued participation [26].

4. Policy recommendations and stakeholder roles

The escalating ecological and economic impacts of IAS in the Mediterranean underscore the need to transition from reactive responses toward comprehensive, forward-looking strategies. Given the region's high exposure to biological invasions, management efforts must prioritize prevention, stable financial support, and coordination across multiple governance levels and stakeholder groups. Enhancing early warning systems, reinforcing legislative frameworks, and securing durable funding arrangements are key pillars for a more effective IAS response.

One of the primary challenges facing economic tools in this context is their dependency on short-term funding cycles, which undermine program continuity and limit their broader adoption. To overcome this, long-term financing frameworks should be institutionalized at the regional level. Economic instruments must also be embedded in robust legal and regulatory structures to ensure their enforceability and impact. Broader application of Pigouvian taxes could serve both to deter high-risk activities and to generate dedicated funds for IAS control. Similarly, performance bonds and environmental/liability insurance schemes can ensure that industries with elevated introduction risks, such as shipping, aquaculture, and ornamental trade, are held financially responsible for mitigation and restoration. Compensation schemes should be expanded, particularly for small-scale fisheries and other directly affected sectors, while removal incentives should be designed with socio-economic resilience in mind.

Effective IAS governance hinges on the active engagement of a diverse set of stakeholders. Governments play a foundational role in establishing legal mandates, allocating resources, and promoting international cooperation. Scientific institutions contribute to the development of early detection systems, control technologies, and evidence-based management strategies. NGOs help bridge science-policy interfaces, promote community awareness, and mobilize support for interventions. Critically, the knowledge and participation of fishers and local communities must be central to policy design and implementation. Their involvement not only improves the uptake of control measures but ensures that financial tools reflect on-the-ground realities.

Given the transboundary nature of marine IAS, and considering the diversity of political, economic, and environmental contexts across the Mediterranean basin, regional cooperation is indispensable. The goal should not be uniformity, but rather the pooling of tools, data, and best practices to help establish common standards while respecting national specificities. Economic instruments should be designed for interoperability across jurisdictions, especially between EU and non-EU Mediterranean countries. Such cooperation requires strengthening existing multilateral institutional frameworks, particularly the Barcelona Convention and its protocols, which could provide a structured framework for harmonizing tax policies, national reforms, and private sector responsibilities.

The ongoing revision of the Mediterranean Strategy for Sustainable Development (MSSD 2026–2035), a key regional framework coordinated by the UN Environment Programme's Mediterranean Action Plan (UNEP/MAP), is already moving decisively in a more pro-active direction.[1] The new MSSD has Objective 5, which emphasizes the transition to a sustainable, green, blue, and circular economy, as well as the advancement of sustainable finance in the region. Among its targets, the strategy encourages a significant share of Mediterranean countries to put in place effective regulatory and policy frameworks, including economic incentives, that support sustainable business models integrating circularity and eco-innovation in both green and blue economies within the coming years. Additionally, there is an ambition for countries across the region to gradually integrate a taxonomy for sustainable investments into their national finance regulations. More specifically the MSSD's Strategic Direction 5.5 will seek to promote an integrated financial ecosystem through the development of a Mediterranean Framework for Green and Sustainable Finance. This framework is intended to channel both public and private capital into sustainable investments by focusing on three pillars: mapping existing financial instruments, identifying environmentally harmful subsidies (EHS) that should be phased-out and scoping and defining a taxonomy of sustainable economic activities. Such a taxonomy, conceived as a financial tool to support ecological and adaptive transition [6], must be defined rigorously and contextually, taking into account the unique economic, social, and environmental characteristics of Mediterranean countries. By setting out clear and context-specific operational criteria, reflecting, for instance, climate vulnerabilities, dependence on natural resources, and the structural features of regional economies, this classification can help clarify investment signals and enhance the consistency of financial practices. By advancing these objectives, the region can further strengthen support for environmentally virtuous financial instruments, including IAS-related ones, fostering a more structured and harmonized approach to tax policies, compensation mechanisms, and private sector responsibilities. The development of national and regional networks for green finance is planned under Strategic Direction 5.5, in order to further enhance collaboration and knowledge-sharing, enabling coordinated action on IAS and other sustainability challenges. Ultimately, the success of the new MSSD will rely on the active engagement of all stakeholders to drive an effective, region-wide transition.

Indeed, as hinted above, beyond the public sector and regional actors, private actors can play a transformative role in IAS management. Public-private partnerships can mobilize resources for research,

[1] The MSSD 2026–2035 was technically validated by the Mediterranean Commission on Sustainable Development, which met in Corinth (Greece) from June 24–26, 2025. It will be formally adopted at COP24 of the Barcelona Convention in December 2025.

surveillance, and removal operations. Businesses may invest in monitoring technologies, sponsor removal campaigns, or incorporate invasive species into new commercial value chains. The growing markets for lionfish and blue crab in the Mediterranean illustrate how ecological threats can, under the right conditions, be converted into economic opportunities. Developing value-added products, encouraging sustainable harvesting, and integrating IAS into culinary traditions can help align economic incentives with ecological goals. Financial mechanisms such as biodiversity offsets, insurance pools, or corporate stewardship programs may further expand funding avenues.

Finally, community engagement and public awareness remain essential. Bridging traditional ecological knowledge with scientific expertise, fostering regional knowledge exchange, and adopting adaptive governance approaches will be key to increasing the resilience of Mediterranean ecosystems. A more holistic model, one that allows for monitoring and sharing feedback and which combines innovation in science, flexibility in policy, and inclusiveness in governance, can provide a roadmap not only for the Mediterranean but for other regions facing the accelerating challenge of marine invasions. In direct support of such a holistic approach, Plan Bleu will actively contribute through its next Work Programme and related research activities. The latter will focus on blended finance approaches that align private investments with sustainability and corporate social responsibility goals, including those relevant to IAS management, followed by work on defining a Mediterranean framework for sustainable activities. Plan Bleu also aims to convene a working group to promote knowledge exchange and best practices among academia, institutional representatives and decision-makers. These efforts will help generate empirically-backed knowledge and data, and foster direct interaction between relevant stakeholders, ensuring that new financial tools and frameworks are informed by robust evidence and practical insights, ultimately strengthening their relevance, ownership and impact across the Mediterranean.

CRediT authorship contribution statement

Nazli Demirel: Writing – review & editing, Writing – original draft, Visualization, Methodology, Data curation, Conceptualization. **Constantin Tsakas:** Project administration, Funding acquisition, Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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